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TO: Division of Water Supply Engineering Staff

THROUGH: Robert W. Hicks, Director
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SUBJECT: Water – Information – UV Disinfection Systems for Public Water Supplies

The purpose of the document attached is to provide guidance for the potential application of ultraviolet light (UV) for drinking water treatment in Virginia. Such guidance is given in the context of the following:

- UV application is in the early developmental stages in the United States. Full-scale experience is not widespread.
- UV has exhibited much promise as a disinfecting agent in drinking water.
- The United States Environmental Protection Agency (USEPA) is developing a guidance manual for the use of UV in drinking water. Any guidance given at this point in time will need to be reviewed and adjusted as necessary relative to this future national guidance document.
- There is an interest in providing addition microbial barriers as the Disinfection By-Product Rule is implemented.

Introduction

Drinking water disinfection using UV has been practiced in Europe for about a decade. However, the application of UV light is a new approach to drinking water disinfection in the United States. UV may offer a cost-effective approach to meeting both disinfection performance and disinfection by-product regulatory requirements and is likely to receive increasing consideration among water system owner/operators and water treatment design engineers as well.

The USEPA Federal Advisory Committee Agreement (FACA), dated April 6, 2000 covers UV disinfection issues to be investigated by USEPA. The Agreement also indicates that USEPA will develop a guidance manual.

The National Water Research Institute and the American Water Works Association Research Foundation have prepared Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse, December 2000, hereinafter referred to as GUIDELINE.A copy is available in the Field Office libraries. The GUIDELINE served as a basis for the development of this document. Further revisions are anticipated as federal guidelines are issued.

Project Review Guidance

General

- Chapter One of the GUIDELINE will be used as a primary reference guide for project review. The guidance provided herein is substantially based on that document, with some additional provisions. (e.g.: UV lamps will not be limited to low pressure type).
- Projects will be reviewed on a case-by-case basis.
- For consideration, a project applicant must submit a Preliminary Engineering Report (PER) for VDH review. The PER need not evaluate alternative disinfectants if UV is being used in combination with an existing primary disinfectant. Applicants should be advised to obtain and review a copy of the GUIDELINE.
- Until such time that national guidance, standards, and/or regulations are in place, **no disinfection credit will be granted** for the use of UV technology in public water systems. Disinfection credit may be given when authoritative guidance has been prepared and adopted.
- Applicants seeking disinfection credit shall provide full-scale component reactor validation testing in accordance with Chapter 3 of the GUIDELINE. An independent testing organization, such as NSF or the German DVGW-Deutscher Verin des Gas- Und Wasserfachees e. V. (The German Association on Gas and Water) or other acceptable certification organizations shall certify each UV disinfection reactor model's performance for the anticipated range of design flows and water quality. Independent certification of sensors will also be required. The necessity of on-site, full-scale validation testing, in accordance with Chapter 3 of the GUIDELINE and 12 VAC 5-590-290 of the *Waterworks Regulations*, will be considered on a case-by-case basis. On-site validation testing may be more difficult logistically as few consultants have the training and expertise to perform the testing. It is anticipated that most equipment will be certified off-site. All systems will need to complete a field-commissioning test as referenced in the Guideline.

  As the information becomes available a list of independently certified UV reactors will be added to the appendix of this document.

- UV reactors are generally installed downstream of filters and followed by a primary disinfectant. When on-site validation is proposed the applicant shall locate the reactor to eliminate other disinfectants or oxidants during the testing period.

Submittal Requirements

For consideration, a project applicant must submit a PER for VDH review containing the following information:

Water Characteristics: The applicant shall identify the expected range of water quantity and quality parameters that can affect UV disinfection system performance (variable transmittance, metals, color, turbidity, hardness, alkalinity and pH). These parameters must be representative of water entering the UV reactor(s).
Treatment Processes**:** The applicant shall provide a schematic diagram of the complete water treatment facilities (including monitoring locations).
UV Disinfection System Design Basis**:** The applicant shall provide a schematic and detailed description of the UV disinfection system. For consideration of future disinfection credits the applicant shall provide sufficient detail to clearly show that the design and operational requirements conform to previously referenced validation requirements. The following minimum information should be provided:

- Reactor and reactor train layout and dimensions, inlet and outlet configuration, reactor train velocity range, and any devices used to modify the flow within the pipes or channels;
- Description of the UV reactor; number, manufacturer and type of UV lamps (including arc length); ballast; modules; banks; and electrical facilities;
- Sleeve configuration and characteristics (e.g.-sleeve material, sleeve diameter, sleeve thickness, and spacing);
- Monitoring and controls, including the number, location, and function of monitoring equipment;
- The water level relative to the UV lamps and level control device;
- The anticipated number of reactor trains in operation under low and peak flow conditions and the corresponding inlet and outlet velocity ranges; and
- Details of the bioassay experiments and the procedure used to derive the operational UV dose (Refer to Chapter 3 of the GUIDELINE for testing protocol information).

The equipment validation report shall provide documentation that the validation requirements have been met. A certificate shall be provided by the manufacturer to verify that the equipment designs, including: lamp spacing, type of lamp, quartz sleeve characteristics, ballast, and sensors is identical to the technology used in the validation testing. The conditions at the point of installation and the variability of water quality and flows shall not exceed those used in the validation testing. Normal scale-up of UV reactors will consist of increasing the number of parallel units rather than increasing the size of a reactor until such time as uniform standards for hydraulic modeling of such demonstrates the efficacy. Hydraulic constraints and design considerations for the installation of parallel reactors shall be in accordance with the Guideline.

When on-site validation testing is performed, a Final Report will be required providing the same information as above.

Monitoring: The applicant shall describe a monitoring program. Where continuous analyses and recording equipment are used, the method and frequency of calibration must be stated. Items to be described in the monitoring section shall include:

- The monitoring system used to determine and record the operational UV dose including equipment and procedures used to monitor and record flow, UV intensity, and UV transmittance,
- The method of monitoring the water level,
- The method of monitoring lamp outages, and
- The sampling location and frequency for collecting microbial samples.

Reliability: The applicant shall describe the proposed UV disinfection system reliability features in detail as referenced in the Guideline to insure the continuous operability of the system. Where disinfection credits are eventually granted and used sufficient redundancy in components shall be provided to allow for the satisfactory operation of the UV system with the largest reactor train out of service.

Alarms shall be used to indicate system failure. The report must state where the alarm will be received, how the location is staffed, and who will be notified. The report must also state the hours that the plant will be staffed.
Sensors, lamps, and ballast shall not be sole source or proprietary, in order to insure the long-term serviceability of the equipment.

Contingency Plan: The applicant shall provide a contingency plan that delineates the actions to be taken for the following conditions:

- Lamp breakage (mercury release, amount of mercury per lamp and containment),
- Low operational UV dose, low UV intensity, and/or high turbidity alarms,
- Failure of the upstream treatment processes or the UV disinfection system, and
- Power supply interruptions.

The person(s) responsible for implementing the contingency plan must be identified along with methods used to notify them.

Operator Certification and Training: The applicant shall present information verifying that the operations staff meet State certification requirements and will receive sufficient training in the operation and maintenance of the UV system.

Additional Design Considerations

UV Sensors -

- Shall have a warranty to operate satisfactorily for a specified life.
- A control reference sensor shall be used to check the UV sensor system.
- The reference sensor and operational sensors shall be able to be calibrated. Calibration of the sensors shall be referenced to an accepted chemical actinometric method.
- Final acceptance for disinfection credit may require duplicate sensors for reliability purposes.

Lamp Recycling and Disposal - Lamp recycling or disposal shall be in accordance with the Department of Environmental Quality's Waste Management Regulations. DEQ advises to check their web site, http://www.deq.state.va.us/waste/fllights.html.

Operation & Maintenance - Operation & Maintenance Supplies to be provided:

- Protective gloves and UV protective glasses
- Appropriate tools and equipment necessary for the maintenance and repairs
- A supply of spare parts

Additional Reference Information

- Additional background information can be obtained at the International UV Association's web site, www.IUVA.org.

- The following documents are available in each Field Office library:
  - EPA Guidance Manual, Alternative Disinfectants and Oxidants, 8 April 1999, Chapter 8;
  - Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse, December 2000, National Water Research Institute, AWWA Research Foundation (This document is referred to as the GUIDLINE);
  - EPA Microbial/Disinfection Byproducts (M-DBP), Federal Advisory Committee, Stage2 M-DBP Agreement In Principle, September 14, 2000;
  - German DVGW-Deutscher Verin des Gas- Und Wasserfachees e. V. (The German Association on Gas and Water) Technical Standard W294, October 1997, as translated for the EPA by James R. Bolton, Bolton Photosciences,Inc.

Appendix - Background Information

Inactivation Modes:
DNA, RNA, other molecules and cell structures can undergo photochemical changes when exposed to UV light. This exposure may damage, inactivate or kill microorganisms. UV light at 253.7 nanometers (nm) has been shown to cause photochemical reactions, which affects the DNA and RNA molecules responsible for genetic codes and the ability of an organism to reproduce. Dimerization (double bond) of the thiamine-thiamine site in DNA is one mode of inactivation frequently mentioned. If sufficient dimerization occurs, the DNA or RNA are not able to replicate, inactivating the organism. Natural light in the range of 350 nm to 450 nm can cause photoreactivation in organisms that have the “photoreactivating enzyme”. However, if sufficient quantity of dimerized sites occur, photoreactivation cannot repair all the sites. Photoreactivation is unlikely to occur at high UV doses, in closed UV reactor vessels and in viruses outside of host cells. Open channel UV disinfection systems are not normally used in water treatment, but if they are considered they need to eliminate photoreactivation.
Many wavelengths other than 253.7 nm may inactivate microorganisms. The germicidal range of wavelengths is generally considered to be between 200 nm and 300 nm. Water absorbs UV light below 200 nm.

System Types:
There are many types of closed vessel and open channel UV systems. The following UV lamp systems are either available or in development:

Low-Pressure*	Eximer (in development)
Low-Pressure, High Intensity*	Pulsed (in development)
Medium-Pressure*	

* these systems use mercury in the lamps

Low-Pressure Systems use lamps similar to fluorescent lamps with quartz glass used for the lamp and outer jacket. The lamps are filled with an inert gas such as argon. They are considered to have a monochromatic light source near 254 nm. The actual range of wavelengths produced by low-pressure systems resembles a narrow bell curve with the peak near 254 nm. This is the system most frequently used to disinfect water and wastewater. The wastewater designs are similar to potable water designs except that potable water generally transmits ≥ 95% (usually closer to 99% transmittance) of the UV light, and the quartz lamp jackets do not usually foul as quickly in potable water. These systems usually have the greatest number of lamps. The lamp temperatures range from 35° to 45° C. They have a long service history and are not very complex in comparison to the other systems.

Low-Pressure, High Intensity lamps are very similar to the low-pressure type but use more energy per lamp and require fewer lamps. Their higher lamp temperatures of 50° to 80° C can slightly increase the rate of fouling. They are more complex than conventional low-pressure systems.

Medium-Pressure lamps also use fluorescent style tubes but emit a broader band of UV wavelengths that may differ with the lamp model and manufacturer. There have been reports of these units imploding in service, releasing mercury. This is thought to have been due to thermal shock where lamps were not maintained in a submerged condition and cold water contacted the hot jacket or because of leaking jacket seals. The reaction of microorganisms may vary due to the wavelength output characteristics of different manufacturer medium-pressure lamps. These systems are more complex than low-pressure systems but require significantly fewer lamps. Lamp temperatures can range from 400° to 800° C. Recent work indicates that the bacteriaphage, MS-2, being considered for surrogate testing purposes, may be sensitive to the lower range of UV light (<230 nm) often produced by medium-pressure lamp systems. This may imply that medium-pressure systems could be more effective against viruses, since MS-2 is thought to be similar to viruses in its response to UV light. One potential problem with medium-pressure systems has been documented. During static startup, as the lamps warm up, all nitrates could be converted to nitrite within the reactor section due to that portion of the light output that extends below 230 nm. During normal operation there is insufficient contact time to effect any appreciable conversion. Normal mixing in a receiving clear well would usually eliminate any concern about exceeding the 1-mg/l nitrite MCL. Systems considering this design may need to evaluate the potential for producing nitrite and develop procedures for discarding or mixing to achieve compliance with the nitrite standard.

Pulsed UV lamps operate in a manner similar to a strobe light or flash lamp. A very intense full spectrum light including both white light and UV light is produced. These lamps generate very high plasma temperatures (12,000° Kelvin) requiring a very clean recirculating cooling water between the lamp and outer jacket. They produce ozone as a by-product. They appear to have the lowest energy consumption and require the least number of lamps. Flow proportional control is a matter of adjusting the strobe rate. These lamps do not use mercury. Current systems may need to replace lamps every 3 months if the maximum strobe rate is used. Other systems will probably need to replace lamps annually.

Eximer- these systems are in early development using an electric discharge to produce the UV light like a laser. They may be able to be tuned to produce very monochromatic or polychromatic light.

Manufacturers are trying to develop mercury-free lamps. Some estimate that in 5 years mercury can be eliminated. Some have developed a mercury trap. No data has been provided on the effectiveness of such mechanisms to contain mercury.

Ballast:

Ballast is a transformer that sends power to the UV lamps. The transformer comes in two types; electronic and electromagnetic. To avoid premature ballast failure they need to be kept at temperatures below 60° C. This may require cooling fans or air conditioning. The electromagnetic type may produce less heat and have a longer life; their use may also result in lower lamp temperatures.

UV Sensors and Calibration:

UV sensors are the primary means of determining the operating status of UV disinfection equipment, because of the difficulty of on-site bioassays and challenge testing. Lamp operating indicators are helpful but cannot determine if the required minimum light intensity is being met. Sensors are generally photocells preceded by UV filters or mirrors and possibly shutters. Some designs allow for sensors to be submerged and others are mounted in windows on the side of the reactor. UV light ultimately degrades sensors so they must periodically be calibrated and replaced. In the event that a sensor indicates that insufficient light intensity is being produced (a common recommended minimum cut off is at 75% of the initial design intensity), an automatic control valve could be shut to contain the flow. The flow could also be diverted to waste or some other acceptable means of containing the flow might be provided depending on the specific application. The location and number of UV sensors must accurately determine conditions in the UV reactor. It is important that sensors have sufficient operating life (the design life should be equivalent or better than the normal lamp life, which is often quoted at 7500 hours for low-pressure lamps). A reference sensor is needed to check the calibration of the operational sensors. Sensors are subject to fouling and must have ready access for cleaning. Automatic wiping devices are available for cleaning of some sensors and lamp jackets.

EPA was requested by FACA to review Germany’s standards, which require uniformity of UV sensors. The advantages include ease of inspection and no problems with orphaned sensors when a sensor system is abandoned or a company goes out of business. Their standard requires a calibrated hand held sensor to check the condition of installed sensors.

Calibration of reference sensors and specifications for sensors and lamps and ultimately the dose should be by chemical actinometry. Chemical actinometry has been used in the nuclear field for some time. It relies on the production of a photochemical product and can be used to detect numerous forms of ionizing radiation. The German standards use the conversion of a buffered solution of uridine to uridine hydrate. This works well in the wavelength range of 240 nm to 290 nm. American researchers are looking at the conversion of potassium iodide to potassium iodate as an actinometer that would incorporate the full range of germicidal wavelengths.

Fouling:

Both UV lamps and sensors are subject to fouling. The primary causes of fouling are the constituents in the water and the lamp jacket temperature. Alkalinity, color, hardness, metal ions (such as iron, manganese and aluminum), and turbidity are of primary concern. pH can affect the dissolution of these constituents and the temperature at the lamp jacket can affect the rate of deposition of these constituents on the quartz lamp jacket. There are automated and manual cleaning systems available to deal with this potential problem. Lamp and sensor cleaning should be required before the lamp output reaches a 25% drop below the initial design intensity. At a minimum, they should be cleaned and calibrations checked quarterly. Lamps, quartz jackets and sensors may need to be replaced annually.

Reactor Designs:

Reactors of many different configurations exist. Generally closed vessels are used for water treatment, because of their small footprint, less chance for operator exposure and because pollutants are not as likely to be introduced. Lamps can be mounted either parallel or perpendicular to the flow. The design must maintain a flooded condition to cool the lamps and prevent lamp jacket failure due to thermal shock. Sensors measuring the UV intensity in one reactor unit must be referenced to that unit since different configurations may result in a different UV dose even using the same number and type of lamps.

Mercury Lamp Breakage:

Lamp breakage is very rare under normal operating conditions with lamps fully submerged. Where rocks or foreign objects can enter the flow stream, screens may need to be provided to protect the lamps. Mercury levels per lamp are reported to range from 30 mg to 1.3 grams depending on the manufacturer. Manufacturers are attempting to reduce mercury levels and may eventually eliminate it.

Mitigating actions or containment of mercury in the event of a rare breakage will need to be addressed. Some UV equipment designs may include a mercury trap since mercury is 13.6 times heavier than water. The effectiveness of such devices will need to be demonstrated. Use of lamps containing the least amount of mercury should be considered.

Lamps may break during change out. Clean-up procedures will need to be included for such events.

List of Independently Certified UV Reactors/UV Sensors:

As information becomes available this list will be updated. Applicants will need to include a copy of Certification and Validation reports with their submittals.